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ABSTRACT

Designed for high school electronics students, this fourth document in a series of six electrical learning activity packages focuses on alternating current-reduced voltage controls. An introductory section gives the objective for the activities, an introduction, and an outline of the content. The remainder of the guidebook is comprised of information sheets and job sheets on topics such as (1) part-winding starting and (2) autotransformer starting. Each job sheet follows a typical format that includes the objective, materials, explanation, procedure, and evaluation questions. (LRA)

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CONNECTICUT STATE DEPARTMENT OF EDUCATION

DIVISION OF VOCATIONAL EDUCATION

HARTFORD

ELECTRICAL EXPERIMENTS

VT - 214 - 12 - 4

PART IV

A-C REDUCED VOLTAGE CONTROLS

CE 026 100

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ELECTRICAL EXPERIMENTS

A-C MOTOR CONTROLS - REDUCED VOLTAGE

Contents

	No. of Pages
Information Sheet - Job 1 - Part-Winding Starting - - - - - - -	3
Job Sheet 1 - Part-Winding Starting - - - - - - - - - - - - - -	3
Job Sheet 2 - Wye-Delta Starting - - - - - - - - - - - - - - - -	6
Information Sheet Jobs 3 and 4 - Autotransformer Starting - -	2
Job Sheet 3 - Autotransformer Starter - Manual - - - - - - - -	4
Job Sheet 4 - Autotransformer Starter - Automatic - - - - - -	4
Job Sheet 5 - Resistance Type Reduced Voltage Starting- - - -	4
Job Sheet 6 - A.C. Dynamic Braking - - - - - - - - - - - - - -	5
Job Sheet 7 - Wound Rotor - Secondary Resistor - Face Plate Type Starting -	4
Job Sheet 8 - Three Phase Wound-Rotor Drum Control- - - - - - -	5
Job Sheet 9 - Three Phase Wound-Rotor Acceleration Control- - -	4
Job Sheet 10 - Synchronous Motor Starting - - - - - - - - - - -	5

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A-C MOTOR CONTROLS - REDUCED VOLTAGE

Information Sheet - Job 1
Page 1 of 3

Part-Winding Starting

Objectives

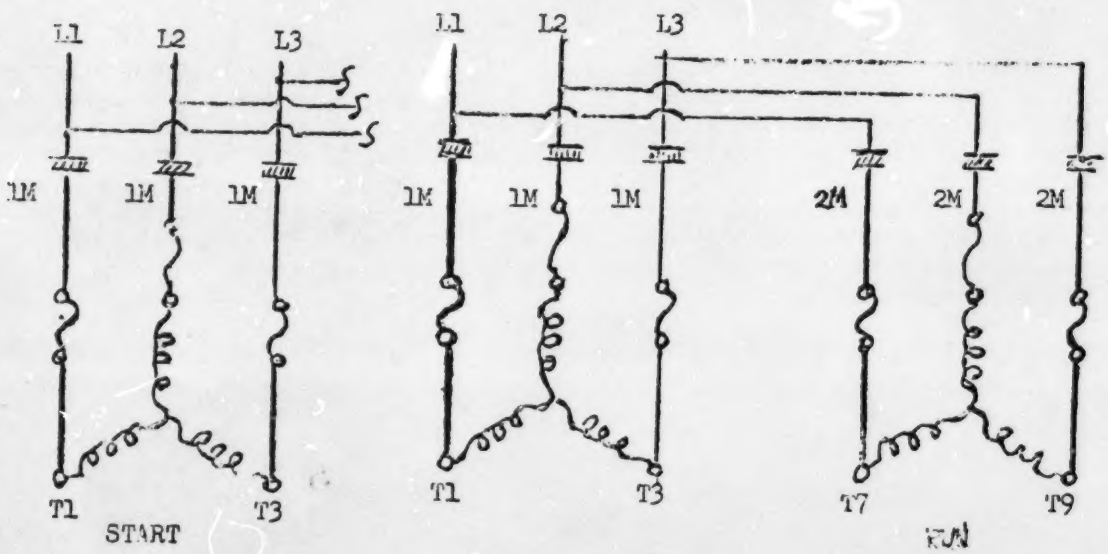
Understanding the principles of part-winding starting circuits.

Part-winding motor starting is used when there is a need to limit either or both the starting current and torque. Typical applications would be fans, blowers, centrifugal pumps, etc.

The starting current is limited to 60 to 70% of normal and the starting torque is reduced to approximately 45%.

A dual-voltage wye connected squirrel cage motor is usually used for this type of starting. A delta connected motor may be used, but it must be specially wound and connected for part-winding starting. If either a wye or delta motor is to be used it should be rated for part-winding starting or the manufacturer consulted. Since some motors are not designed to be used as part-winding devices, noise, vibration and overheating may result from using a regular dual-voltage motor.

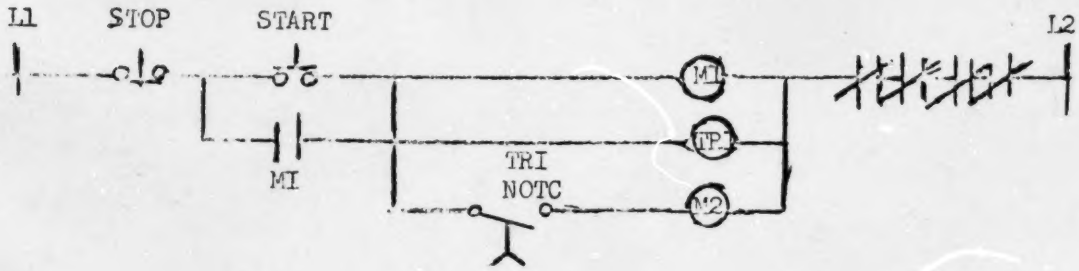
The dual-voltage wye connected motor has two identical windings that are connected in series for the higher voltage and in parallel for the lower voltage. The phrase "Part-winding starting" is the result of using only one of the wye windings for starting and then both wye windings in parallel for running. Therefore, the starting and running voltage of the motor will be the lower of the dual-voltage ratings (i.e., a 220/440V motor will start and run at 220V).



Notice that there must be at least four motor running overcurrent protection devices and since the two wye windings are separately protected the rating of the overload devices will be one-half the full load motor current rating at the lower voltage, (i.e. a 220/440V motor, full load current 3.5/1.8 rating would require 1.8 amp protection).

Because smaller starters and overloads are used, the branch-circuit overcurrent device must be smaller. Therefore dual-element fuses are usually required. The NEMA sizes for part-winding starters are not the same as for across the line starters. Consult a motor control catalog for proper horsepower ratings and sizes.

The control circuit of a part-winding starter consists of the Start-Stop buttons, operating coil M1 which closes the starting contactor and normally-open auziliary contacts M1, operating coil M2 for the second stage contactor, overload switches, and time delay relay TR 1 with normally-open-time-to-close contacts. The time delay should be limited to no more than four seconds to prevent overheating.



Pressing the start buttons energizes coils TR1 and MI closing the starting contactor and holding contacts MI. After a time delay the timer contacts TR1 close to energize coild M2 closing the run contactor, which connects the second half of the wye windings in parallel with the first half used for starting. When the control circuit is de-energized by pressing the stop button, opening the overload switches or a loss of voltage both contactors open and the motor will not start again until the start button is pressed. The normally-open time-to-close contacts in the timing relay open instantaneously when the timing relay is de-energized.

Questions

1. For what conditions would part-winding motor control be used?
2. Show the normal connections for a dual voltage wye connected motor for both voltage ratings.
3. Show the motor connections when the dual voltage wye connected motor is used for part-winding starting.
4. What should the operating time of the time-delay relay be?
5. How large should the motor running overcurrent protection be in part-winding starters?
6. Why are dual element fuses needed for branch circuit overcurrent protection?

References

American Electricians' Handbook, 8th Ed., Croft, McGraw-Hill
Electric Motor Control, Aldrich, Delmar
Electrical Control Systems in Industry, Charles S. Siskind
Electric Motor Control Fundamentals, McIntyre

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A-C MOTOR CONTROLS - REDUCED VOLTAGE

Job Sheet 1
Page 1 of 3

Part-Winding Starting

Objectives

1. Installation of wiring and associated equipment for part winding starting.
2. Application of N.E.C. requirements.

Materials Required:

3 Ø Dual Voltage squirrel cage motors
1 Two step part-winding motor starter
1 Start-Stop push button station
Motor branch circuit discount with overcurrent protection

Explanation

This job involves the complete installation from feeders to the motor using part-winding starting with one remote start-stop push button station. The fundamentals of this type of motor control are explained in the preceding information sheet. As you follow the directions of this job sheet be sure to make the correct connections and follow all precautions. Failure to do so can be costly.

Procedure

1. Read Information Sheet for this job. Be sure you understand how part-winding starting control circuits operate.
2. Have instructor assign motor to be controlled.
3. Submit for approval a line diagram showing the sizes of equipment, wire and overcurrent protection from feeder termination to motor. (Double check valves of overcurrent devices).
4. Submit a conduit diagram showing all equipment, conduit and wire sizes as required by N.E.C.
5. Submit for approval a wiring diagram from feeder termination to motor.
6. After having diagrams approved, obtain materials and proceed to mount equipment.

CAUTION:

Be sure supply switch to your job is open and tagged. Using voltmeter, check load side of switch between phase legs and each phase leg to ground to insure that there is no voltage on your circuit conductors. At the same time check the line side of the switch to be sure the voltage to your circuit corresponds to the voltage ratings of your equipment.

7. Make the following checks after equipment is mounted:

   a) Proper ratings (voltage and current).
   b) Contact surfaces in controller and push button station for alignment and condition of wear (i.e., pitted, burned, etc.)
   c) Proper contact tension.
   d) Free operation of all moving parts.
   e) Condition of flexible shunts.
   f) Condition of arc chutes and barriers.
   g) Worn or broken mechanical parts.
   h) Correct overload devices (See Information Sheet).
   i) Correct coil voltage (contactors and timing relay).

8. Proceed to wire all equipment and controls as shown in your approved diagrams.

   Caution:

   Be sure that motor leads are correctly identified and comply with NEMA requirements. If there is any doubt, disassemble the motor and check with compass and D.C. supply that the windings are parallel that should be. If correctly identified, proceed as follows using a continuity tester to check each conductor between motor and controller before connecting.

   a) Connect together T4, T5, T6.
   b) Connect T1 motor lead to T1 controller terminal.
   c) Connect T2 motor lead to T2 controller terminal.
   d) Connect T3 motor lead to T3 controller terminal.
   e) Connect T7 motor lead to T7 controller terminal.
   f) Connect T8 motor lead to T8 controller terminal.
   g) Connect T9 motor lead to T9 controller terminal.
   h) Check that L1 will be connected to T1 and T7.
   i) Check that L2 will be connected to T2 and T8.
   j) Check that L3 will be connected to T3 and T9.

   It is very important that there be no error in these connections.

9. After all wiring is completed and connections made, check the following:

   a) Connections and wiring correspond to your diagram.
   b) All splices are mechanically and electrically tight and properly insulated.
   c) All terminal connections are tight.
   d) Wires to not interfere with moving parts.
   e) Motor properly lubricated and not binding.

10. Have your Instructor check the completed installation and secure his approval BEFORE energizing the circuit.

11. Be sure there is no danger to others should the motor unexpectedly start when you close the disconnects.

12. Remove your tag and close disconnects to energize the circuit. Make the following checks:
    a) Press Start button, starting contactor only should close.
    b) Time the delay between the closing of the start contactor and run contactor. (Should not be more than 4 seconds).
    c) After both contactors are closed use a clamp on ammeter and check the current in each motor lead.
    d) Press the Stop button, both contactors should open immediately.
    e) With stop button depressed press Start button, nothing should be energized.

13. Upon completion of job, carefully dismantle equipment and be sure it is in good condition for the next student.

Questions

1. What would be wrong if both contactors closed at the same time when the Start button is pushed?

2. Explain why the motor running overcurrent protection rating is not the same as the full load current rating of the motor.

3. What would happen if motor leads T8 and T9 were interchanged?

References

Allen-Bradley, Bulletin 736
Cutler - Hammer Control Catalog
Electric Motor Control, Aldrich, Delmar
Electrical Motor Control Fundamentals, McIntyre

Wye-Delta Starting

Objectives:

1. Understanding the principles of Wye-Delta starting and control.
2. Ability to make complete motor installation of Wye-Delta starting.
3. Ability to apply N.E.C. requirements to work.

Materials Required:

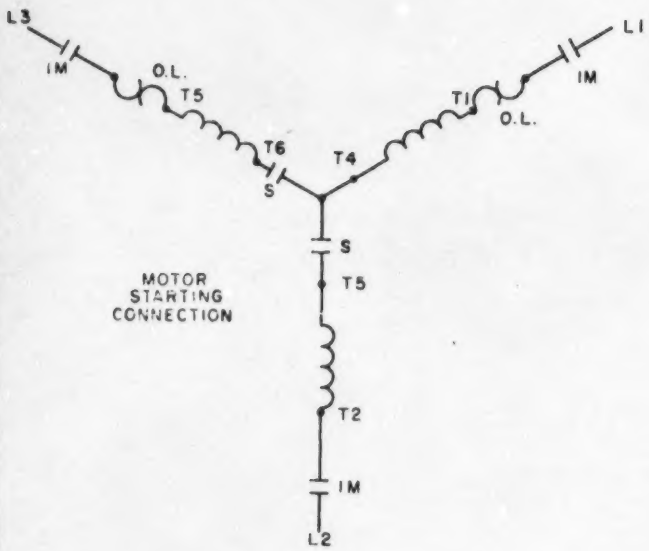
1 - Start-Stop momentary contact push button station
1 - Wye-Delta motor and starter
Other materials to be determined by student.

Explanation:

The Wye-Delta method of reduced voltage starting provides a low cost method of limiting starting current with a high starting torque per ampere. During the starting cycle the windings are Wye connected and then reconnected Delta for running. A disadvantage is that the motor is disconnected from the line during the transition period.

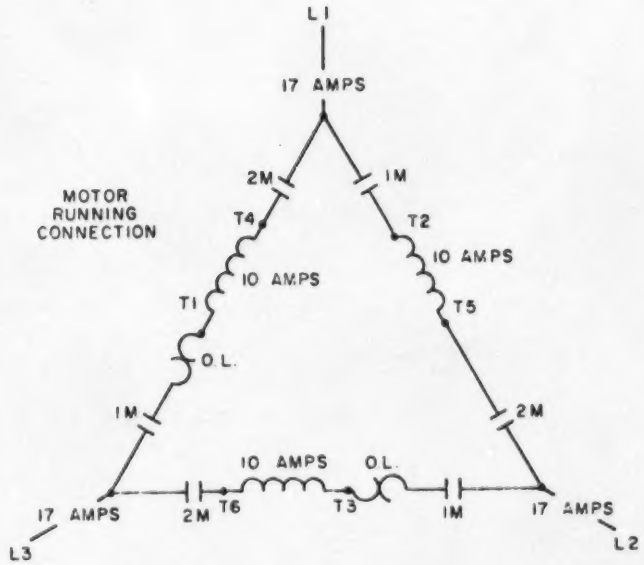
The motor used for this type starting is similar in construction to a standard equirrel cage delta wound motor except that both ends of each of the three windings (total of six wires) are brought out to the terminal junction box. Since the synchronous speed of a star-delta motor depends on the number of poles and the frequency of the supply, the motor speed will be the same with either connection.

The motor branch circuit overcurrent protection shall be based on the nameplate full load current in accordance with Article 430 of the N.E.C. The motor running overcurrent protection shall be based on 58% of the rated delta connected full load current and for maximum protection there should be three overcurrent devices, one for each winding. Figs. 1A and 1B with Table 1C will help in understanding why the overloads are rated for 58%. Note that in Fig. 1B the heaters are connected in the motor winding circuit and <u>not</u> in the line circuit.



Motor Starting

FIGURE 1A



Motor Running

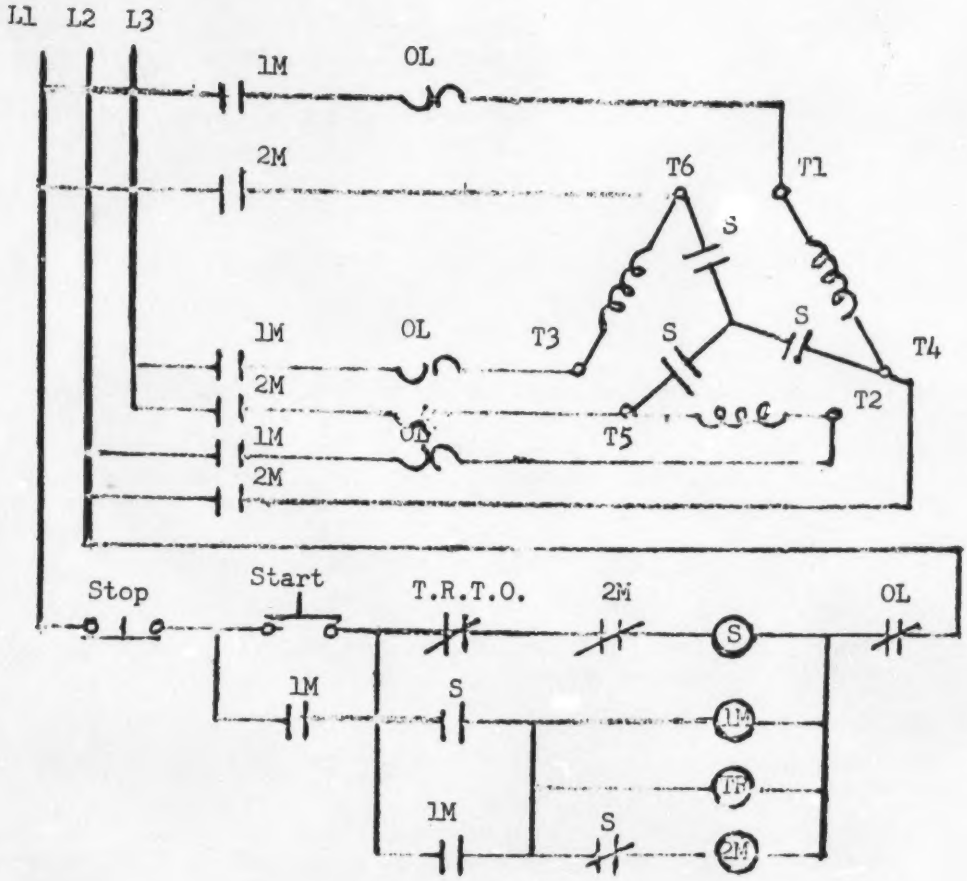
FIGURE 1B

Table 1C

	WYE - FIG 1A	DELTA - FIG 1B
Line Voltage	220v	220v
Voltage Across Each Coil	127v	220v
Current in Each Coil	5.8a	10a
Line Current Each Phase Leg	5.8a	17a

CONTROL CIRCUIT

Figure 2



Control Circuit: pushing the Start button completes the circuit for coil S from L1, through the Stop, Start, normally-closed-time-to-open Time-relay contacts (TR), normally-closed auxiliary contacts 2M, coil S, overload contacts to L2. When coil S is energized contactor S closes, the normally-closed (S) contacts in series with coil 2M open, preventing coil 2M from being energized until the N.C.T.O. (TR) contacts open and de-energize coil S. Also when soil S is energized the N.O. contact (S) in series with coils 1M and TR close energizing both coils. Coil 1M now closes the contactor 1M to start the motor in the Wye connection and also closes the N.O. contacts in parallel with the start button to establish the holding circuit, and the N.O. contacts in 1M in series with coil 2M to maintain the circuit after coil S has been de-energized. After a time delay of about 4 seconds the N.C.T.O. (TR) contacts open de-energizing coil S, opening the Wye connection at T4, T5 and T6 and allowing coil M2 to be energized closing the 2M contactor, thereby connecting the windings in delta.

Procedure

1. Have instructor assign motor to be controlled and classification of motor.

2. Submit for approval a line diagram showing the sizes of equipment, wire, and overcurrent protection from feeder termination to motor.

3. Submit for approval a conduit diagram showing all equipment, conduit and wire sizes as required by N.E.C.

4. Submit for approval a wiring diagram from feeder termination to motor.

5. After having diagrams approved, obtain materials and proceed to mount equipment.

Caution:

Be sure supply switch to your job is open and tagged. Using voltmeter check load side of switch between phase legs and each phase leg to ground to be sure there is no voltage on your circuit conductors. At the same time check the line side of switch to be sure the voltage to your circuit corresponds to the voltage ratings of your equipment.

6. Making the following checks after equipment is mounted:
   a) Proper rating - voltage, current and size of starter.
   b) Contact surfaces in controller and p.b. station for proper alignment and condition of wear (i.e., pitted, burned, etc.).
   c) Proper contact tension.
   d) Free operation of all moving parts; push button, contacts, coil armatures, etc.
   e) Check mechanical interlock between contactors S and 2M by manually closing one contactor and trying to close the other, then reverse procedure.
   f) Condition of flexible shunts.
   g) Condition of arc chutes or barriers.
   h) Worn or broken mechanical parts.
   i) Correct coil voltage.
   j) Correct motor running overcurrent devices.
      Note: 58% of delta full load current rating.
   k) Check and compare the internal wiring of the controller with your diagram.

7. Proceed to wire all equipment and controls as shown in your approved diagrams. Caution: Use a continuity tester to verify terminal lead designations between controller and motor as you connect each lead.

8. After all wiring is completed and connections made, check the following:

   a) Connections and wiring correspond to your diagrams.

   b) All splices are mechanically and electrically tight and properly insulated.

   c) All terminal connections are tight.

   d) Wires do not interfere with moving parts.

   e) Motor is properly lubricated and not binding.

9. Have your instructor check the completed installation and secure his approval BEFORE energizing the circuit.

10. Be sure there is no danger to others should the motor unexpectedly start when you close the disconnects.

11. Remove your tag and close disconnects to energize circuit. Make the following checks:

    a) Press Stop button and hold while pushing Start button. Controller should not operate.

    b) Press Start button and then Stop button to check direction of rotation. If the rotation is wrong, interchange L1 and L3 on the Line side of the controller. Will usually be easiest at the motor disconnect switch. After making the change re-check rotation.

    c) Press Start button - Contactors 1M and S should close. Time intervals between start and run (Controller is in "Run" when contactor S opens and 2M closes with 1M remaining closed). Time should not exceed 5 seconds.

    d) With clamp-on ammeter check and record the current in T1, T2 and T3. (Should be approximately the same in each and approximately 58% of the current in L1, L2 and L3). Record the current in L1, L2 and L3.

12. Upon completion of job carefully dismantle equipment and be sure that it is left in good condition for the next student.

Questions

1. Explain why the voltage is only 127v across each Wye connected winding when 220v is connected to the motor.

2. What is the ratio of line current with the Wye connection to the line current with the delta connection?

3. How many motor running overcurrent protection devices are required?

4. What should the rating of these overcurrent devices be?

5. Compare the difference in motor running overcurrent protection between the Part-Winding starting and the Wye-delta starting.

6. In Part 11.d under Procedure you recorded the currents of T1, T2, T3, L1, L2, L3. Compare the current in T1 and L1 and explain the ratio between them.

7. What is meant by open transition from start to run?

References

American Electricians' Handbook, 8th Ed. Croft, McGraw-Hill

Electrical Motor Controls and Circuits, Fuchs and Garstang, Howard W. Sam & Co., Inc.

Electric Motor Control, Aldrich, Delmar

Cutler-Hammer Control Catalog

National Electrical Code

Electrical Motor Control Fundamentals, McIntyre

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A-C MOTOR CONTROL - REDUCED VOLTAGE

Information Sheet - Job 3 and 4
Page 1 of 2

Autotransformer Starting

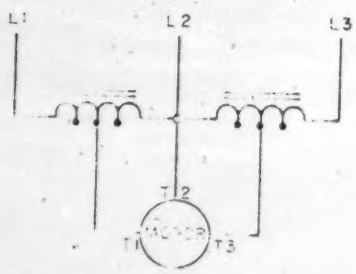
Objectives

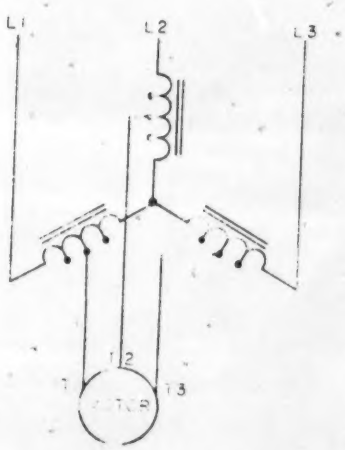
1. Understanding of autotransformer starting.
2. Appreciation of advantages and disadvantages of autotransformer starting.

Explanation

Another means of reducing a high starting current in three phase squirrel cage motors is the autotransformer starter, also referred to as a compensator or auto-starter. The advantage of the autotransformer is that the transformer allows a higher current on the motor side than on the line side. This lower line current causes less line disturbance while providing a higher motor current for greater starting torque. Another advantage is gained when compared to a resistor type reduced-voltage starter. There is an appreciable power loss using resistors to obtain reduced-voltage while the transformer provides the lower voltage with minimum power loss. The autotransformers are in the motor circuit only during starting and in the run position the motor is connected across the line. Manual or Magnetic controllers may be used.

Figures 1A and 1B are line diagrams of the basic power circuit connections for autotransformer starting. Figure 1A shows the use of two autotransformers which will produce a motor voltage imbalance and approximately a 10% variation in torque. The two transformer controller is common to the manually operated starter. Figure 1B shows the use of three autotransformers connected in Wye for starting. The motor voltage and current are balanced and there is no variation in torque.





The taps on the transformers provide for 50%, 65% and 80% of line voltage. Normally the manufacturer supplies the controller with connections made to the 65% tap, but these may be easily changed by the installing electricians to meet the specific requirements.

Article 430 of the National Electrical Code allows shunting of the motor running overcurrent protection device during the starting period if the starter ismanually controlled, including magnetic starters with push button control, provided it cannot remain in the start position, but prohibits shunting with automatic starters controlled by timers, temperature control, etc. The N.E.C. requires that there be overcurrent protection in the motor circuit not to exceed 400% of the full load motor current during the starting period if the motor running overcurrent protection is shunted. All manual (hand controlled) starters in use today shunt the running overcurrent protection during the starting period, therefore, the branch circuit, short circuit protection shall not exceed 400% of full load current. Most of the magnetic type autotransformer starters have the running overcurrent device in the circuit during starting.

A disadvantage of the manual and many of the magnetic auto-starters is that there is an open transition. The motor is momentarily disconnected from the line during the change from start to run and this can be objectionable because a sharp current spike may be created when the run contacts close, causing line disturbances. To overcome this in the magnetic auto-starter a third contactor is used to open the common connection to the autotransformer before the run contactor is energized, thereby leaving the autotransformer winding a series reactor. The run contactor can then close without opening the start contactor, resulting in a closed-circuit transition.

To reverse the motor if the direction of rotation is incorrect, the interchange of loads may be made at the motor or line terminals.

Questions

1. What voltage taps are standard on autotransformer starters?
2. By what other means is autotransformer starting known?
3. State N.E.C. requirements that shall be complied with when the motor running overcurrent protection is shunted during starting.
4. What is meant by open circuit transition? What are its disadvantages?
5. What is meant by closed circuit transition? What are its advantages?

References

Allen-Bradley Motor Control Catalog
A. C. Fundamentals, Duff, Delmar
Controllers for Electric Motors, James and Markle, McGraw-Hill
Electric Motor Controls, Aldrich, Delmar
National Electrical Code
Electrical Control Systems in Industry, Charles S. Siskind
Electric Motor Control Fundamentals, McIntyre

Job Sheet 3
Page 1 of 4

Autotransformer Starting - Manual

Objectives

1. Ability to make a complete motor installation with manual autotransformer starting.
2. Ability to apply N.E.C. requirements to work.

Materials Required:

1 - Three phase squirrel cage motor
1 - Manual autotransformer starter
1 - Three-pole fused motor disconnect switch
Other materials to be determined by student

Explanation

The basic principles of auto-starting are explained in the Information Sheet for Jobs 3 and 4. This job involves the manual controlled starter. The starting handle is mechanically interlocked so that it cannot be thrown to the run position until after the start cycle. To start the motor the handle is pulled toward the operator and held. Figure 1A shows the internal starter connections for start. L1 and L3 are connected to the 100% taps of their respective autotransformers, L2 is connected to the 0% end of both transformers and T2, T1 and T3 are connected to the 65% taps. The overloads, stop button and holding coil are not connected in the circuit. The handle must be held in the start position until a signal, usually a bell, indicates that the starting time has elapsed and the handle may then be thrown to run. The timing device is usually a pneumatic timer that is actuated by moving the handle to the start position. After the timing period, which is adjustable, is completed the interlock is opened to allow the handle to be moved to the run position. Because the motor is disconnected from the line between start and run, the handle should be moved rapidly to the run position to minimize the open transition time. Figure 1B shows the internal connections for the run position. The transformers have been disconnected from the circuit, the motor is across the line and the holding circuit is completed through the Stop button, coil S and overload contacts. The handle is spring loaded to return to the off position from either start or run. In the run position the handle is electro-mechanically held by solenoid S. To stop the motor the Stop button is pressed or the handle may be moved of the off position. Coil S also acts as an undervoltage protection since it will allow the handle to return to the off position if the voltage is too low to hold the solenoid in. Any number of stop buttons may be connected in series to open the manual controlled starter, but the starting operation must be at the controller.

A.C. Motor Control - Reduced Voltage

Figure 1A

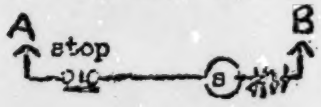
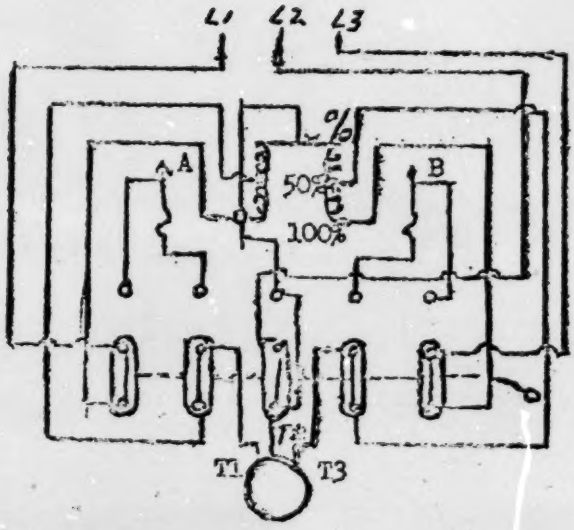
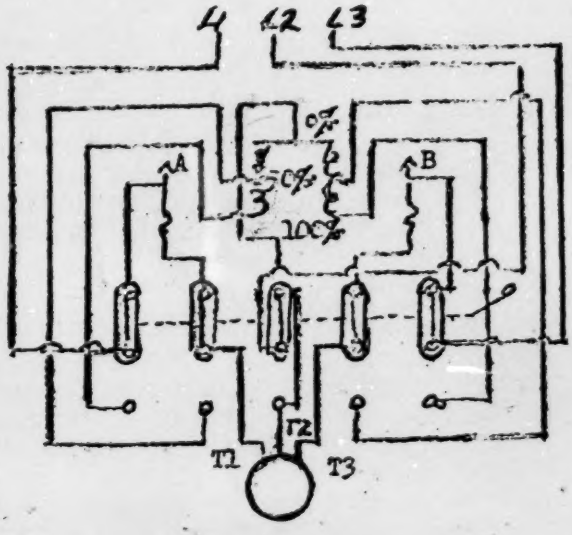


Figure 1B





Procedure

1. Read Information Sheet on Autotransformer Starting an introduction on this sheet.
2. Have instructor assign motor to be controlled.
3. Submit for approval a line diagram showing the sizes of equipment, wire and overcurrent protection from feeder termination to motor.
4. Submit for approval a conduit diagram showing all equipment, conduit and wire sizes as required by N.E.C.
5. Submit for approval a wiring diagram from feeder termination to motor.
6. After having diagrams approved, obtain materials and proceed to mount equipment.

CAUTION: Be sure supply switch to your job is open and tagged. Using voltmeter check load side of switch between phase legs and each phase leg to ground to be sure there is no voltage on your circuit conductors. At the same time check the line side of switch to be sure the voltage to your circuit corresponds to the voltage ratings of your equipment.

7. Make the following checks after equipment is mounted:
   a) Proper ratings - voltage, current and size of starter.
   b) Contacts surfaces in controller and p.b. station for proper alignment and condition of wear (i.e., pitted, burned, etc.).
   c) Proper contact tension.
   d) Free operation of all moving parts; push buttons, contacts, coil armature, etc.
   e) Check mechanical interlock by trying to put handle in run position.
   f) Condition of flexible shunts.
   g) Condition of arc chutes or barriers.
   h) Worn or broken mechanical parts.
   i) Correct coil voltage.
   j) Correct overload protection devices.
   k) Check and compare the internal wiring of the controller with your diagram.
   l) If contacts are oil immersed, check that the oil is at the proper level.

8. Proceed to wire all equipment and controls as shown in your approved diagrams.

9. After all wiring is completed and connections made, check the following:
   a) Connections and wiring correspond to your diagrams.
   b) All splices are mechanically and electrically tight and properly insulated.
   c) All terminal connections are tight.
   d) Wires do not interfere with moving parts.
   e) Motor properly lubricated and not binding.
   f) Branch circuit prot-ction properly sized. (Overloads shunted during start).

10. Have your instructor check the completed installation and secure his approval BEFORE energizing the circuit.

11. Be sure there is no danger to others should the motor unexpectedly start when you close the disconnects.

12. Remove your tag and close disconnects to energize circuit. Make the following checks:
   a) Move handle toward run position, the interlock should prevent this.
   b) Pull handle to start, after timer indicates rapidly move the handle to the run position, handle should remain in run.
   c) Pull handle to off position to stop motor.
   d) Repeat 12b and then use Stop button to open controller.

13. Upon completion of job carefully disconnect the equipment. Be sure equipment is left in good condition.

Questions

1. Study the mechanical interlock that prevents the handle from being put in the run position until after the start cycle. Make a sketch showing how the interlock works.

2. Why is it important that the handle be moved rapidly from start to run?

3. Is there any disadvantage in flexibility of control stations with manual auto-starters?

References

Controllers for Electric Motors, James & Markle, Mc-Graw Hill Book Co.

Electrical Motor and Controls Circuits, Fuchs and Garstang, Howard W. Sams & Co. Inc.

Electrical Control Systems in Industry, Charles S. Siskind

CONNECTICUT STATE VOCATIONAL SCHOOLS

A-C MOTOR CONTROL - REDUCED VOLTAGE

Job Sheet 4
Page 1 of 4

Autotransformer Starting - Automatic

Objectives

1. Ability to make a complete motor installation using automatic autotransformer starting.
2. Ability to apply N.E.C. requirements to the job.

Materials Required:

1 - Three-phase squirrel cage motor
1 - Three-pole fused motor disconnect switch
1 - Autotransformer type starter with closed circuit transition
Other materials to be determined by student

Explanation

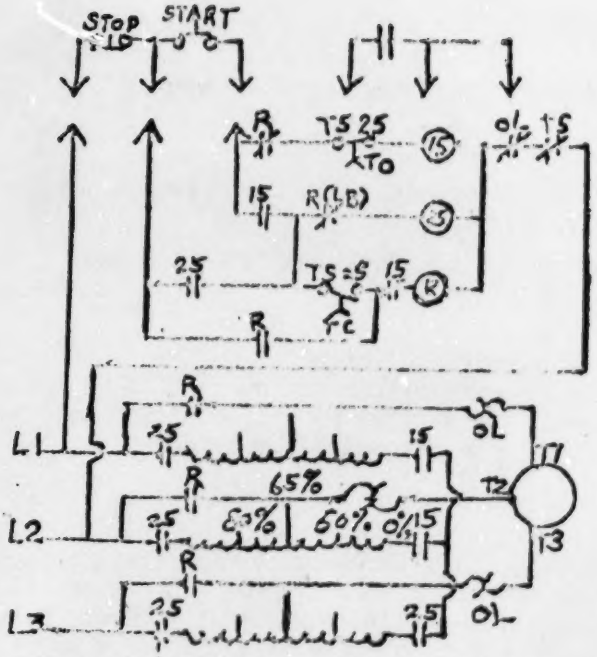
This job involves the installation of a magnetic autotransformer Starter to have automatic or two wire control. (Check N.E.C., Art. 100, Definitions, for the meaning of automatic) Since the same starter may be used for automatic or push-button control, both types of control are shown in Figure 1. The basic principles of autotransformer starting are explained in Information Sheet for Jobs 3 and 4.

Follow the explanation by tracing the circuits in Figure 1. The following is for two wire control:

Starting: L1 through pilot contacts, N.C. R contacts, TS-2S T.O. contacts, coil 1S, O.L., N.C.T.S. to L2. Energizing coil 1S closes 1S contacts which connect the 0 ends of the three transformers together, opens the electrical interlock (N.C. 1S) for coil R and closes the N.O. contacts in series with coil 2S allowing coil 2S to be energized. Contactor 2S closes connecting the line to each transformer (completing the Wye connection) and closes the N.O. contacts in parallel with the 1S contacts in the transition holding circuit. The motor is now operating on the voltage determined by the tap connections.

Transition: Timer opens TS-2S T.O. contacts de-energizing coil 1S allowing the N.C. 1S contacts in coil R circuit to close. Coil 2S remains energized through its holding contacts and N.C. R (L.B.) contacts. TS-2S T.C. contacts close energizing coil R and closing R contactor. This establishes a hold circuit through N.O. R contacts and de-energizes coil 2S by opening N.C. R (L.B.) contacts. During the time interval between the opening of the 1S contactor and the closing of the R contactor the autotransformers are connected as series reactors with the motor.

Running: When contactor R closes the motor is across the line and will continue to operate until the control circuit is opened.



Timer TS2S is located on and triggered by contactor 2S. Normally closed contacts T.S. are part of a thermal switch which protects the autotransformer from overheating. Contactors 1S and R are mechanically interlocked.

Procedure

1. Read Information Sheet on Autotransformer Starting.
2. Have instructor assign motor to be controlled and classification of motor duty.
3. Submit for approval a line diagram showing the sizes of equipment, wire, and overcurrent protection from feeder termination to motor.
4. Submit for approval a conduit diagram showing all equipment, conduit and wire sizes as required by N.E.C.
5. Submit for approval a wiring diagram from feeder termination to motor.
6. After having diagrams approved, obtain materials and proceed to mount equipment.

   CAUTION: Be sure supply switch to your job is open and tagged. Using voltmeter, check load side of switch between phase legs and each phase leg to ground, to be sure there is no voltage on your circuit conductors. At the same time, check the line side of the switch to be sure the voltage to your circuit corresponds to the voltage ratings of your equipment.

7. Make the following checks after equipment is mounted:

   a) Proper ratings (voltage and current).
   b) Contact surfaces in controller and p.b. stations for proper alignment and condition of wear (i.e., pitted, burned, etc.).
   c) Proper contact tension.
   d) Free operation of all moving parts; push buttons, contacts, coil armatures, etc.
   e) Check mechanical interlock by manually closing one contactor and then try to close other. Reverse procedure.
   f) Condition of flexible shunts.
   g) Worn or broken mechanical parts.
   h) Condition of arc chutes or barriers.
   i) Correct overload protection devices.
   j) Correct coil voltage.
   k) Check and compare the internal wiring of the controller with your diagram.

8. Proceed to wire all equipment and controls as shown in your approved diagrams.

9. After all wiring is completed and connections made, check the following:

   a) Connections and wiring correspond to your diagram.
   b) All splices are mechanically and electrically tight and properly insulated.
   c) All terminal connections are tight.
   d) Wires do not interfere with moving parts.
   e) Motor properly lubricated and not binding.

10. Have your instructor check the completed installation and secure his approval BEFORE energizing the circuit.

11. Be sure there is no danger to others should the motor unexpectedly start when you close the disconnects.

12. Remove your tag and close disconnects to energize circuit. Make the following checks:

    a) Close pilot control switch and observe operation, time the starting period.
    b) Open the pilot switch to stop the motor.
    c) Reset the pneumatic timer for a two seconds increase in the starting time. Repeat step 12a.

13. De-energize and disconnect your equipment using care to insure that everything is in working order for the next student.

Questions

1. Why is a mechanical interlock used between contactors 1S and R when they are electrically interlocked?

2. Explain what affect the autotransformers have on the circuit when they are connected as series reactors during the transition time.

3. If the motor taps are connected for 50% of line voltage, what will be the starting torque?

References

Controllers for Electric Motors, James & Markle, McGraw-Hill

Electrical Motor Controls and Circuits, Fuchs & Garstang, Howard M. Sams & Co. Inc.

Electric Motor Controls, Aldrich, Delmar

Electrical Control Systems in Industry, Charles S. Siskind

Electric Motor Control Fundamentals, McIntyre

Job Sheet 5
Page 1 of 4

Resistance Type Reduced Voltage Starting

Objectives

1. Understanding of resistance type starting.
2. Ability to make complete motor installation using resistance type reduced voltage starting.
3. Ability to apply N.E.C. requirements to work.

Materials Required

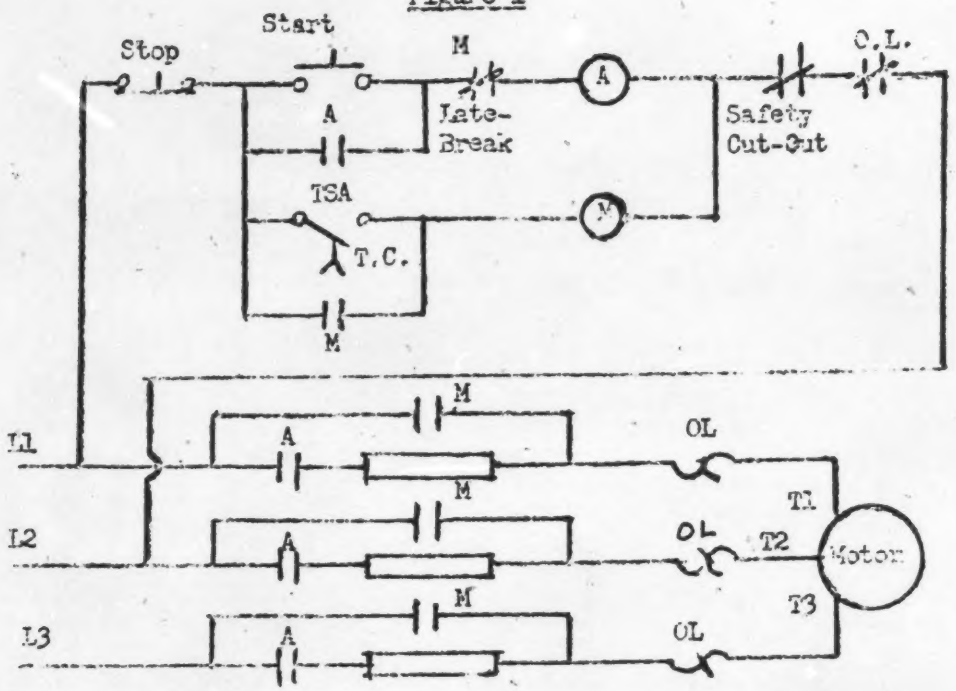
1 - Three phase squirrel cage motor
1 - Three-pole fused motor disconnect
1 - Resistance type reduced voltage starter and start-stop push button station
Other materials to be determined by student

Explanation

A simple and direct method of starting a three phase squirrel cage motor on reduced voltage is to connect resistors in series with the motor windings. The resistance may be shunted in a single step or in increments for multistep step starting. When all resistance has been shunted the motor will be running on line voltage. This type of starting provides low starting current and torque with smooth acceleration to running speed. The major disadvantage of primary resistor starting is the high power of I^2R losses in the resistors during the starting cycle.

Figure 1 shows the motor control and power line diagram for a single step start to run. Pressing Start button energizes coil A through N.C.M. contacts, N.C. safety cut-out contacts and O.L. contacts closing contactor A, establishing a holding circuit through contactor A in parallel with Start button and connecting the motor to the line through the sropping resistors. The motor is now operating at reduced voltage for starting. As the motor accelerates the line current drops, decreasing the voltage drop (IR) across the resistors increasing the voltage at the motor. The timing of this starting cycle is controlled by a pneumatic timer which is mounted on and actuated by the closing of Contactor A. At the end of the preset time contacts TSA T.C. close completing the circuit for coil M which closes contactor M, which shunts the resistors and connecting the motor across the line. The Late-Break M contacts open de-energizing coil A which disconnects the resistors from the power circuit. Pressing the Stop button, opens the control circuit, disconnecting the motor from the line. The N.C. Safety Cut-Out contacts are thermal controlled to protect resistors from overheating.

Figure 1



A multistep start would operate on the same principle. A timing device and set of contacts would be required for each step. Instead of closing the main contactor the first timer would close a contactor to shunt only a part of the resistance. This would continue until the last step when the remaining resistance would be shunted by the closing of the main contactor putting the motor across the line.

Procedure

1. Have instructor assign motor to be controlled and classification of motor duty.
2. Submit for approval a line diagram showing the sizes of equipment, wire and overcurrent protection from feeder termination to motor.
3. Submit for approval a conduit diagram showing all equipment, conduit and wire sizes as required by N.E.C.
4. Submit for approval a wiring diagram from feeder termination to motor.

5. After having diagrams approved, obtain materials and proceed to mount equipment.

   CAUTION: Be sure supply switch to your job is open and tagged. Using voltmeter, check load side of switch between phase legs and each phase to ground, to be sure there is no voltage on your circuit conductors. At the same time check the line side of the switch to be sure the voltage to your circuit corresponds to the voltage ratings of your equipment.

6. Make the following checks after equipment is mounted:

   a) Proper ratings - voltage and current.
   b) Contact surfaces in controller, jog relay and p.b. station for alignment and condition of wear (i.e., pitted, burned, etc.).
   c) Proper contact tension.
   d) Free operation of all moving parts; push buttons, contacts, coil armatures, etc.
   e) Condition of flexible shunts.
   f) Worn or broken mechanical parts.
   g) Condition of arc chutes or barriers.
   h) Correct overload protection devices.
   i) Correct coil voltage.

7. Proceed to wire all equipment and controls as shown in your approved diagrams.

8. After all wiring is completed and conn-ctions made, check the following:

   a) Connections and wiring correspond to your diagram.
   b) All splices are mechanically and electrically right and properly insulated.
   c) All terminal connections are tight.
   d) Wires do not interfere with moving parts.
   e) Motor properly lubricated and not binding.

9. Have your instructor check the completed installation and secure his approval BEFORE energizing the circuit.

10. Be sure there is no danger to others should the motor unexpectedly start when you close the disconnects.

11. Remove your tag and close disconnects to energize circuit. Make the following checks:

    a) Keep Stop button depressed and push Start button. Nothing should happen. (Checking that control circuit is in series with Stop button).

    b) Press Start button. Contactor A should close. Time interval between closing of contactor A and contactor M. When contactor M closes the motor should be operating across the line and contactor A drops out.

c) Press Stop button, motor should stop.
d) Reset timing for starter cycle to be two seconds longer. Repeat steps 11b and 11c.
e) Connect 3 - 15 watt bulbs, rated for the full line voltage, between T1 - T2, T2 - T3. Repeat steps 11b and 11c, watching the brightness of the bulbs vary as the motor picks up speed during the starting cycle.

12. Upon completion of job carefully dismantle equipment and be sure that it is left in good condition for the next student.

Questions

1. Explain why the voltage drop across the resistors in a 2 point primary resistor starter decreases during the starting cycle.

2. How many contactors and timers would be required to have four steps of resistance in the starting cycle?

3. What is the advantage of multi-step resistors for starting?

References

A. C. Fundamentals, Duff, Delmar

American Electricians' Handbook, 8th Ed.; Croft, McGraw-Hill

Electrical Motor Control, Aldrich, Delmar.

National Electrical Code, N.F.P.A.

Electrical Control Systems in Industry, Charles S. Siskind

Job Sheet 6
Page 1 of 5

A. C. Dynamic Braking

Objectives

1. Understanding the wiring of A.C. Dynamic braking.
2. Ability to install a complete motor installation with dynamic braking.
3. Ability to apply N.E.C. requirements to work.

Materials Required

Three phase squirrel cage motor
Three-pole fused motor disconnect switch
Pneumatic timer-relay with "Off-delay"
Reversing magnetic starter with electrical and mechanical interlock
N.O. auxiliary contacts for starter
Stop-Start momentary contact push button station with start button having N.O.-N.C. contacts
Full wave dry type rectifier with transformer and relay to control transformer primary.
Other materials to be determined by student.

(Note: Consult your instructor as to the correct size D.C. power supply to be used with the size motor you have been assigned. Normally the D.C. voltage will be approximately 10% of the motor running voltage).

Explanation

Dynamic braking is the method of retarding the motor speed or of completely stopping the motor through making the motor operate as a generator with a resistance load. For dynamic braking of a squirrel cage induction motor, a source of D.C. excitation must be provided. Three methods of providing this D.C. excitation are, (1) from a separate source, (2) from rectifiers connected to the motor A.C. line circuit, and (3) by means of capacitors. This job will utilize method 2, using full wave or bridge connected dry type rectifiers.

Dynamic braking is accomplished by disconnecting the motor from the supply and connecting one phase of the motor primary winding to one terminal of the D.C. and the other two phase windings through resistors to the other D.C. terminal. The motor will then be driven by the load as a generator and will load itself through the induced current in the motor secondary flowing through the squirrel cage winding. A smooth positive stop is obtained because the braking torque decreases rapidly as the speed approaches zero and is adjustable by the use of taps on the loading resistors. The D.C. excitation must be removed at the end of the braking period, or the windings will overheat. One brake stop is equivalent to a normal start, therefore the allowable number of starts without overheating the motor must be adjusted or reduced.

Advantages:

a. Cannot reverse the motor.
b. Smooth positive retardation without the shock of a mechanically set brake, and less severe than plugging.
c. Braking torque easily adjustable.

Disadvantages:

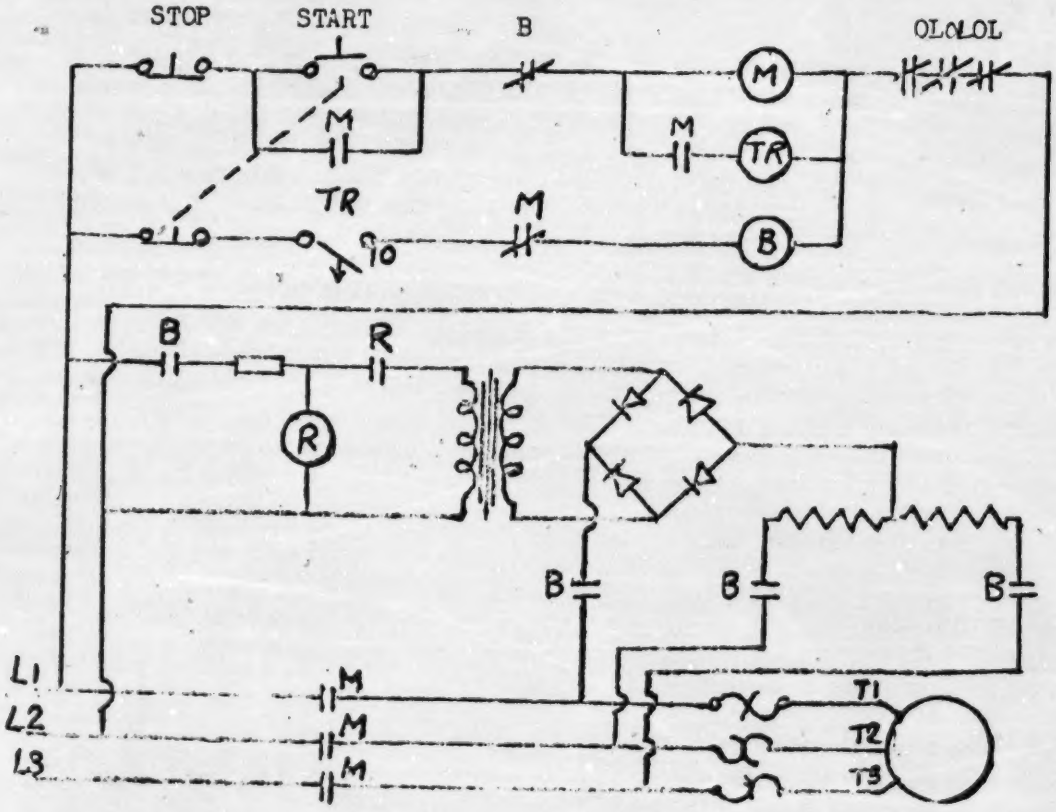
a. Requires D.C. source.
b. No braking in event of power failure.
c. More expensive type equipment than plugging and other types. Prohibitive with large motors.
d. Is not a holding brake once the motor is stopped.

Any type of starting circuit may be combined with dynamic braking. The essential point is that the starting and running circuits be interlocked with the D.C. Braking circuit, either mechanically or electrically and preferably both. For this job a modified reversing across-the-line starter will be used.

Control Circuit: To run the Start button is pressed, opening the Brake coil circuit and completing the main contactor coil (M) circuit from L1 through Stop, Start, N.C. (B) interlocking contacts, coil M, O.L. switches to L2. The holding circuit is established by the N.O. (M) contacts in parallel with the Start button, the N.C. (M) interlock contacts for coil B open and the time-delay is energized closing the T.O. (M) contacts. The motor is now across the line.

To stop, the Stop button is pressed, opening the running contactor, disconnecting the motor from the line and completing the Brake coil circuit through the N.C. (M) contacts. Contactor B closes, connecting the motor to the D.C. excitation supply. Also completing the relay control circuit in the rectifier supply through N.O. (B) auxiliary contacts (normally the holding contacts). The Brake contactor remains closed until the T.O. contacts open the control circuit at which time the motor should have stopped. It is important that the timer be adjusted so that the D.C. excitation voltage is not left connected to the motor once it has stopped. Therefore this type of control would be unsatisfactory on a motor that has a wide variation in stopping loads since the time to stop will vary with the load.

Note that the overloads are in the circuit both during running and braking. This is to insure that additional heat is not developed in the motor by braking if the motor is already overheated to the point where the overloads would open the control circuit.



Procedure

1. Read Information Sheet for Job 2, A.C. Across-the -Line Control, Low Voltage Control Circuit.
2. Read Information Sheet for Jobs 7 to 11, incl., A.C. Across-the-Line Control, Reversing Magnetic Controllers.
3. Have instructor assign motor to be controlled and classification of motor duty.
4. Submit for approval a line diagram showing the sizes of equipment, wire and overcurrent protection from feeder termination to motor.
5. Submit for approval a conduit diagram showing all equipment, conduit and wire sizes as required by N.E.C.
6. Submit for approval a wiring diagram from feeder termination to motor.

7. After having diagrams approved, obtain materials and proceed to mount equipment.

   CAUTION: Be sure supply switch to your job is open and tagged. Using voltmeter, check load side of switch between phase legs and each phase to ground, to be sure there is no voltage on your circuit conductors. At the same time check the line side of the switch to be sure the voltage to your circuit corresponds to the voltage ratings of your equipment.

8. Make the following checks after equipment is mounted:

   a) Proper ratings (voltage and current).
   b) Contact surfaces in controller, jog relay and p.b. station for alignment and condition of wear (i.e., pitted, burned, etc.).
   c) Proper contact tension.
   d) Free operation of all moving parts; push buttons, contacts, coil armatures, etc.
   e) Condition of flexible shunts.
   f) Worn or broken mechanical parts.
   g) Condition of arc chutes or barriers.
   h) Correct overload protection devices.
   i) Correct coil voltage, controller, timing relay and transformer relay.
   j) Transformer properly rated.

9. Make the following modifications to the controller:

   Remove jumpers between line terminals on left hand contactor and right hand contactor.

   Label line side of right hand contactor contacts B1, B2, B3.

   Remove leads from N.O. contacts on B contactor that would normally be used as the holding contacts for that contactor. These contacts will be used to control the relay circuit for the rectifier.

   Mount N.O. auxiliary contacts on line contactor to control time-relay.

10. Proceed to wire all equipment and controls as shown in your approved diagrams.

11. After all wiring is completed and connections made, check the following:

    a) Connections and wiring corresponds to your diagram.
    b) All splices are mechanically and electrically tight and properly insulated.
    c) All terminal connections are tight.
    d) Wires do not interfere with moving parts.
    e) Motor properly lubricated and not binding.

12. Have your instructor check the completed installation and secure his approval BEFORE energizing the circuit.

13. Be sure there is no danger to others should the motor unexpectedly start when you close the disconnects.

14. Remove your tag and close disconnects to energize circuit. Make the following checks:

    a) Press Start button. Contactor M and timer-relay should close and remain closed. Coils B and R remain de-energized.
    b) Press Stop button. Contactor M should open and contactor B and relay R should be energized establishing the D.C. supply to the motor. As the motor stops the T.O. contacts should open, de-energizing coils B and R.
    c) If the Brake circuit does not open as the motor stops, reset the time delay and repeat steps a and b. Repeat until the desired results are obtained.

15. After you have completed your job, carefully dismantle equipment and replace the original wiring in the controller. Be sure equipment is in good condition for the next student.

Questions

1. Explain why there are not the usual holding contacts for the braking contactor coil.

2. What size fuse is required for protection of the transformer if placed in a) the primary, b) the secondary?

3. Explain how the braking affect can be controlled by varying the resistance in the D.C. circuit.

References

Allen-Bradley Bulletin 705

Allen-Bradley Motor Control Catalog

American Electricians' Handbook, 8th Ed. Croft, McGraw-Hill

Electric Motor Controls, Aldrich, Delmar

National Electrical Code, N.F.P.A.

Electric Motor Control Fundamentals, McIntyre

Job Sheet 7
Page 1 of 4

Wound Rotor - Secondary Resistor - Face Plate Type Starter

Objectives

1. To connect a face-plate secondary resistor type starter and associated equipment for control of a wound-rotor induction motor.
2. Application of National Electrical Code requirements.

Materials Required

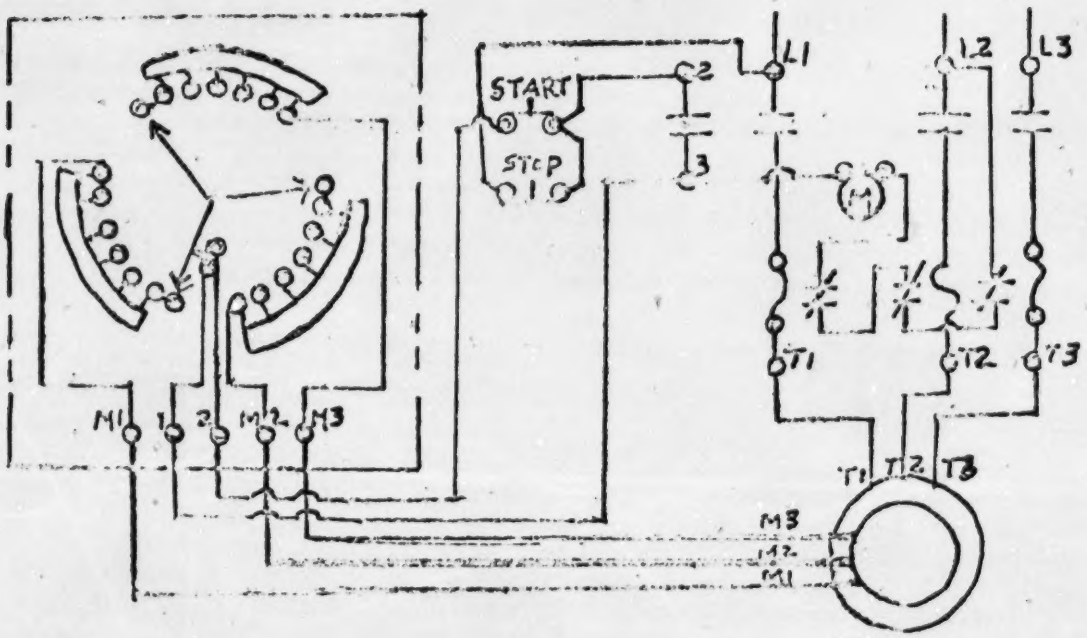
Three phase wound-rotor induction motor
Three-pole fused motor disconnect switch
Across-the-line starter
Manual sliding contact type (face plate) secondary resistor type regulator
Start-Stop momentary contact push button station
Other materials to be determined by student

Explanation

A three-phase wound rotor induction motor is similar to a squirrel cage motor except that the rotor has three windings which are connected to slip rings on the rotor shaft. Carbon brushes riding on the slip rings connect the windings to the external circuit conductors. Variable resistors are connected in series with each rotor winding and then connected in Wye to provide starting and speed control. As the resistance in the "secondary" windings decrease the speed will increase until the three rotor windings are shorted together, at which time the motor will be operating at normal speed.

Wound rotor or secondary resistor starters have resistors that are rated for starting duty only and should not be used for speed control. Regulators are designed with continuous duty resistors for starting and speed control and should be used where speed regulation is required.

This job will be the installation of a face plate type wound rotor starter. The manual sliding contact type of starter has an electrical interlock that is used in the control circuit of the magnetic starter. The magnetic starter is used to control the primary circuit of the motor.



Note in the diagram that unless the wiper arms are maximum counter clockwise with maximum resistance in the secondary the primary control cannot be energized. The primary controller is an across the line control. With the wiper arms maximum counter clockwise the Start button is pressed closing the main contactor. The face plate control is then manually turned clockwise to decrease the secondary resistance until the resistance is shorted in the motor is running at normal speed.

The National Electrical Code, Article 430-32 (d), states, "The secondary circuits of wound rotor alternating-current motors, including conductors, controllers, resistors, etc., shall be considered as protected against overcurrent by the motor-running overcurrent device". Some manufacturers do provide temperature switches to prevent overheating of the resistors.

Procedure

1. Read Information Sheets on A.C. Across the Line Controllers.
2. Have instructor assign motor to be controlled and classification of motor duty. Also direction of rotation to be considered forward.
3. Submit for approval a line diagram showing the sizes of equipment, wire and overcurrent protection from feeder termination to motor, including secondary control.
4. Submit for approval a conduit diagram showing all equipment, conduit, and wire sizes as required by N.E.C.

5. Submit for approval a wiring diagram from feeder termination to motor.

6. After having diagrams approved, obtain materials and proceed to mount equipment.

   CAUTION: Be sure supply switch to your job is open and tagged. Using voltmeter check load side of switch between phase legs and each phase leg to ground to be sure there is no voltage on your circuit conductors. At the same time check the line side of the switch to be sure the voltage to your circuit corresponds to the voltage ratings of your equipment.

7. Make the following checks after equipment is mounted.

   a) Proper ratings - voltage, current and size of starter.
   b) Contact surfaces in controller and push button station for proper alignment and condition of wear (i.e., pitted, burned, etc.).
   c) Proper contact tension.
   d) Free operation of all moving parts, push buttons, contacts, coil armatures, etc.
   e) Check electrical interlock on regulator.
   f) Condition of flexible shunts.
   g) Condition of arc chutes or barriers.
   h) Worn or broken mechanical parts.
   i) Correct overload protection devices.
   j) Correct coil voltage.
   k) Check and compare the internal wiring of the controller and regulator with your diagram.

8. Proceed to wire all equipment and controls as shown in your approved diagrams.

9. After all wiring is completed and connections made, check the following:

   a) Connections and wiring correspond to your diagram.
   b) All splices are mechanically and electrically tight and properly insulated.
   c) All terminal connections are tight.
   d) Wires do not interfere with moving parts.
   e) Motor properly lubricated and not binding.

10. Have your instructor check the completed installation and secure his approval BEFORE energizing the circuit.

11. Be sure there is no danger to others should the motor unexpectedly start when you close the disconnects.

12. Remove your tag and close disconnects to energize circuit. Make the following checks:

    a) Move wiper arm in regulator to mid point of range and depress the Start button. Nothing should happen. (check of electrical interlock).

    b) Move regulator to start position and press Start button. Main contactor should close and motor start. Slowly move regulator control to run position, watch motor speed increase.

13. Upon completion of job carefully dismantle equipment and be sure it is left in good condition for the next student.

Questions

1. What is the purpose of the electrical interlock in the face plate secondary controller?

2. Explain how under voltage protection is provided.

3. What might be the reasons for the N.E.C. not requiring overcurrent protection in the secondary circuits?

4. Explain why decreasing the resistance in the secondary increases the motor speed.

References

American Electricians' Handbook, 8th Ed., Croft, McGraw-Hill

Electric Motor Controls, Aldrich, Delmar

National Electrical Code, N.F.P.A.

Electric Motor Control Fundamentals, McIntyre

Job Sheet 8
Page 1 of 5

Three Phase Wound-Rotor Drum Control

Objectives

1. Understanding of drum type control of secondary resistance with a three phase wound rotor induction motor.
2. Ability to make a complete motor installation for a wound-rotor induction motor using a drum type controller for controlling the secondary resistance.
3. Ability to apply N.E.C. requirements to work.

Materials Required

Three phase wound-rotor induction motor
Drum type secondary resistance controller
Across-the-line magnetic starter
Start-Stop momentary contact push button station
Three-pole fused motor disconnect switch
Other materials to be determined by student

Explanation

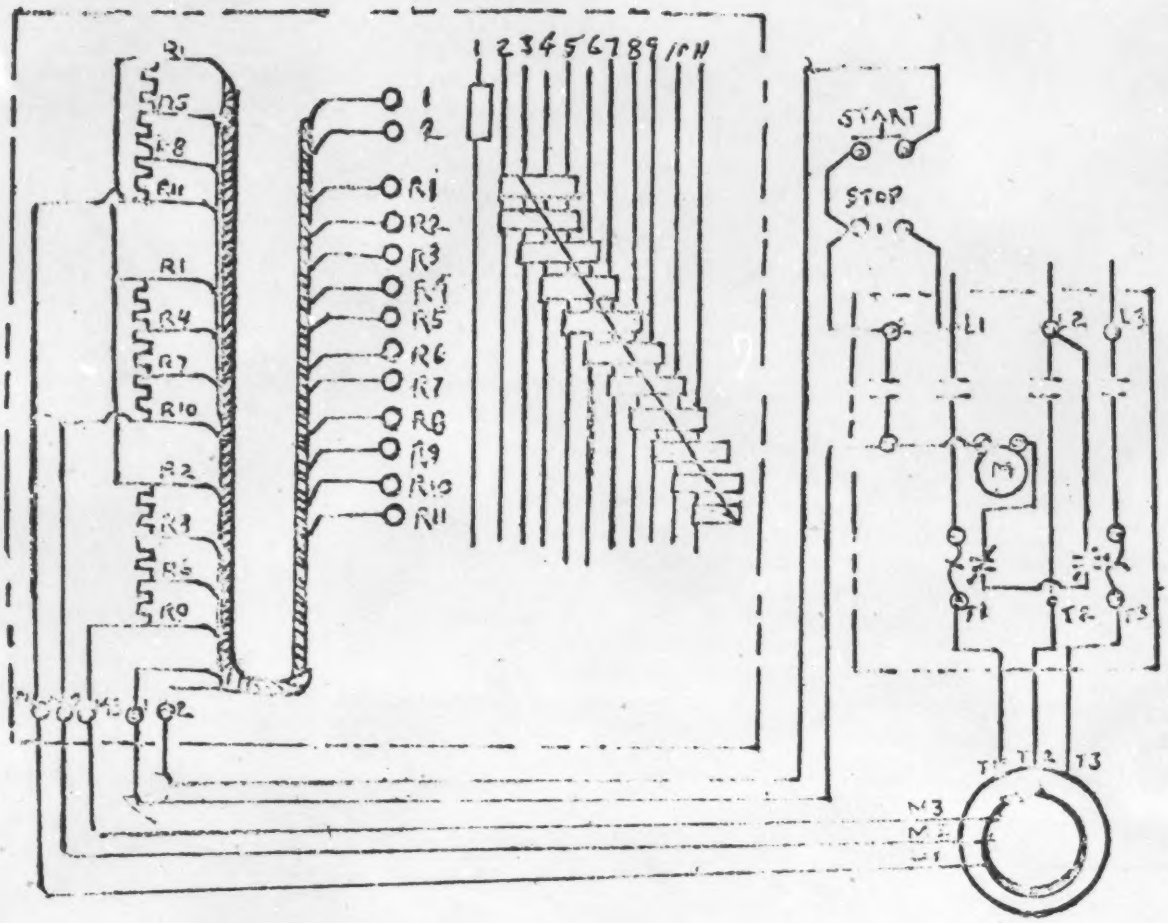
The basic principle of resistance connected in series with the secondary or rotor windings for reduced current starting and speed control of a wound-rotor induction motor is the same regardless of the manner in which the resistance is connected or controlled. As the resistance is decreased in the secondary, the motor speed increases. When all resistance has been shorted the motor operates as a squirrel-cage induction motor.

This job involves the use of a drum type control for controlling the secondary resistance. The drum control is not used to control the starter or primary circuit except for the interlock (Contacts 1 and 2) which is connected in the control circuit of the magnetic starter for the primary. Unless the drum control is in the "Off" or maximum resistance position the magnetic starter cannot be closed. Note in the diagram that each winding has three resistors connected in series with the windings and then are Wye connected. The movable contacts on the drum are electrically connected and are so arranged that as the drum is rotated each position shorts out one resistor. This method differs from the face-plate type of control where the three resistors are shorted simultaneously, one in each rotor lead. The unequal resistance in each rotor lead in the drum type control is not detrimental. The following table will help you understand how this shorting is accomplished. Also note that the shorting contacts on the rotor of the drum control do not continue to short the preceding R terminals, but that the previous portion of the resistance is still shorted by the present position of the controller. Be sure you understand why.

HANDLE POSITION	TERMINALS SHORTED	RESISTORS IN CIRCUITS
1 - Start	1, 2	All
2 -	R1, R2	All
3 -	R1, R2, R3	R3 to R9, R1 to R10, R1 to R11
4 -	R1, R2, R3, R4	R3 to R9, R4 to R10, R1 to R11
5 -	R1, R2, R3, R4, R5	R3 to R9, R4 to R10, R5 to R11
6 -	R3, R4, R5, R6	R6 to R9, R4 to R10, R5 to R11
7 -	R4, R5, R6, R7	R6 to R9, R7 to R10, R5 to R11
8 -	R5, R6, R7, R8	R6 to R9, R7 to R10, R8 to R11
9 -	R6, R7, R8, R9	-- R7 to R10, R8 to R11
10 -	R7, R8, R9, R10	-- -- R8 to R11
11 -	R8, R9, R10, R11	-- --- ---

The primary control is an across the line starter with Start-Stop push button control and electrical interlock with the drum controller. To reverse the motor any two starter leads may be interchanged. Therefore, if reversing control is required a reversing across the line magnetic controller may be used with the same drum controller. The precaution in so doing would be that the electrical interlock in the drum controller be in series with the Stop button and be common to both Forward and Reverse contactors.

Figure 1



Procedure

1. Read Information Sheets on "A.C. Across the Line Controllers and Control Circuits.
2. Have instructor assign motor to be controlled and classification of motor duty.
3. Submit for approval a line diagram showing the sizes of equipment, wire and overcurrent protection from feeder termination to motor.
4. Submit for approval a conduit diagram showing all equipment, conduit and wire sizes as required by N.E.C.
5. Submit for approval a wiring diagram from feeder termination to motor including secondary control.

6. After having diagrams approved, obtain materials and proceed to mount equipment.

   CAUTION: Be sure supply switch to your job is open and tagged. Using voltmeter, check load side of switch between phase legs and each phase to ground, to be sure there is no voltage on your circuit conductors. At the same time check the line side of the switch to be sure the voltage to your circuit corresponds to the voltage ratings of your equipment.

7. Make the following checks after equipment is mounted:

   a) Proper ratings (voltage and current).
   b) Contact surfaces in controller, contactor and push button station for alignment and condition of wear (i.e. pitted, burned, etc.).
   c) Proper contact tension.
   d) Free operation of all moving parts; push button, contacts, coil armatures, etc.
   e) Condition of flexible shunts.
   f) Worn or broken mechanical parts.
   g) Condition of arc chutes or barriers.
   h) Correct overload protection devices.
   i) Correct coil voltage.
   j) Compare the internal wiring of the drum controller and the magnetic starter with your diagram. Be sure that all wiring is connected correctly.

8. Proceed to wire all equipment and controls as shown in your approved diagrams.

9. After all wiring is completed and connections made, check the following:

   a) Connections and wiring correspond to your diagram.
   b) All splices are mechanically and electrically tight and properly insulated.
   c) All terminal connections are right.
   d) Wires do not interfere with moving parts.
   e) Motor properly lubricated and not binding.

10. Have your instructor check the completed installation and secure his approval BEFORE energizing the circuit.

11. Be sure there is no danger to others should the motor unexpectedly start when you close the disconnects.

12. Remove your tag and close disconnects to energize circuit. Make the following checks:

    a) With handle of drum controller on position 3 press Start button. Nothing should happen (check of interlock).

    b) Place drum control handle in Start position, press Start Button. Magnetic contactor should close and remain closed and motor starting and operating with maximum resistance in secondary.

    c) Decrease resistance one step at a time, checking motor speed and current at each step.

    d) Press Stop button. Motor should stop and not be able to start again until drum controller is reset to start.

Questions

1. Explain the difference between a drum-type and face-plate type secondary resistance controller.

2. Why is it possible to use a single drum type controller with a forward-reverse starter? What would happen if the drum-controller was reset to start and the reverse button pushed before the motor had stopped turning in the forward direction?

3. Explain why the shorting contacts in the drum do not have to maintain continuous contact with all resistor terminal contacts.

4. Why is the interlock on the drum controller so important for starting?

References

American Electricians' Handbook, 8th Ed., Croft, McGraw-Hill

Electric Motor Control, Aldrich, Delmar

National Electrical Code, N.F.P.A.

Electrical Control Systems in Industry, Charles S. Siskind

Job Sheet 9
Page 1 of 4

Three Phase Wound-Rotor Automatic Acceleration Control

Objectives

1. Ability to make a complete wound-rotor motor installation using secondary resistance automatic acceleration control.

2. Ability to apply N.E.C. requirements to work.

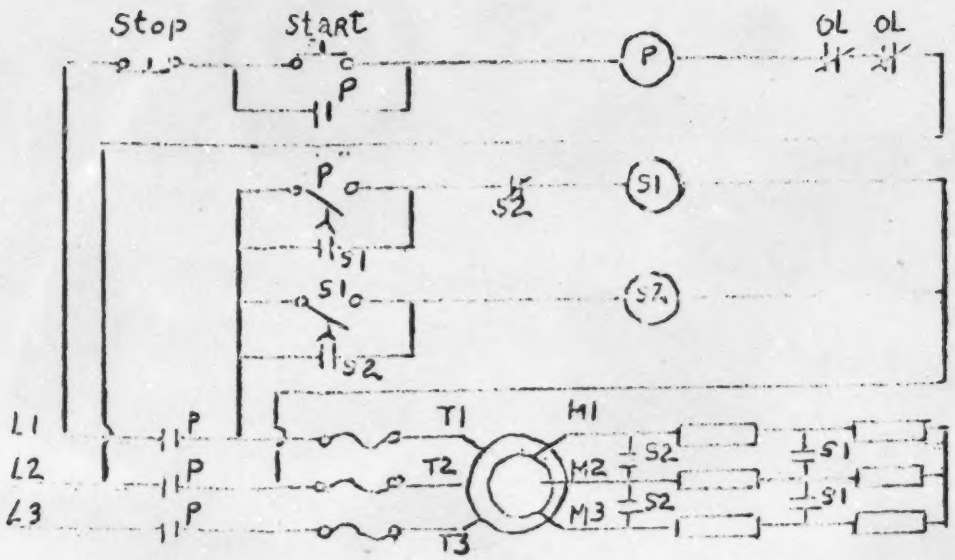
Materials Required

Three phase wound-rotor motor
Three-pole fused motor disconnect
Secondary-resistance automatic acceleration type starter
Momentary contact Start-Stop push button station
Other materials to be determined by student

Explanation

Automatic secondary resistor starters for wound-rotor motor control consist of an across-the-line starter for connecting the motor primary to the line and one or more accelerating contactors to automatically short out the secondary resistors in steps as the motor speed increases. The timing of the individual steps is usually controlled by adjustable pneumatic relays. Once these relays have been adjusted to the desirable time interval the starting time will be the same regardless of the variations in motor load. It is important to realize that this type of starter is designed for starting and accelerating the motor to its operating speed, but cannot be used for speed control. This is because the resistors are designed for short duty cycles associated with starting only and not for continuous duty as required for speed control. Overcurrent protection for the secondary resistors and secondary circuit conductors is provided by the motor-running overcurrent protection in the primary circuit as allowed by the N.E.C.

The control circuit principles in this job are similar to Job 4 (automatic primary resistance-reduced voltage starting). The diagram for this job shows a three point acceleration, (1) maximum resistance, (2) one-half resistance, (3) no resistance, secondary loads shorted. Note that the number of accelerating contactors is one less than the number of starting points. When the start button is pressed there is maximum resistance in the secondary and the primary starter closes, connecting the motor primary to the line and activating the first timer. After the preset elapsed time the N.O.T.C. contacts P close to energize the first shorting contactor (S1) which shorts out the first set of resistors and starts the second timer. After second elapsed time timer contacts (S1) N.O.T.C. close, energizing contactor S2 which shorts out the second set of resistors and allows the motor to operate at full speed. The N.C. (S2) contacts in the S1 coil circuit are late break. This is to insure that contactor S2 has closed before contactor S1 opens.



Procedure

1. Read Information Sheets on A.C. Across the Line Controllers.

2. Have instructor assign motor to be controlled and classification of motor duty. Also direction of rotation to be considered forward.

3. Submit for approval a line diagram showing the sizes of equipment, wire and overcurrent protection from feeder termination to motor, including secondary.

4. Submit for approval a conduit diagram showing all equipment, conduit, and wire sizes as required by N.E.C.

5. Submit for approval a wiring diagram from feeder termination to motor, including secondary.

6. After having diagrams approved, obtain materials and proceed to mount equipment.

   CAUTION: Be sure supply switch to your job is open and tagged. Using voltmeter, check load side of switch between phase legs and each phase leg to ground to be sure there is no voltage on your circuit conductor. At the same time check the line side of the switch to be sure the voltage to your circuit corresponds to the voltage ratings of your equipment.

7. Make the following checks after equpment is mounted.
   a) Proper ratings - voltage, current and size of starter.
   b) Contact surfaces in controller and push button station for proper alignment and condition of wear (i.e., pitted, burned, etc.).
   c) Proper contact tension.
   d) Free operation of all moving parts, push buttons, contacts, coil armatures, etc.
   e) Condition of flexible shunts.
   f) Condition of arc chutes or barriers.
   g) Worn or broken mechanical parts.
   h) Correct overload protection devices.
   i) Correct coil voltage.
   j) Check and compare the internal wiring of the controller with your diagram.

8. Proceed to wire all equipment and controls as shown in your approved diagrams.

9. After all wiring is completed and connections made, check the following:
   a) Connections and wiring corresponds to your diagrams.
   b) All splices are mechanically and electrically tight and properly insulated.
   c) All terminal connections are tight.
   d) Wires do not interfere with moving parts.
   e) Motor properly lubricated and not binding.

10. Have your instructor check the completed installation and secure his approval BEFORE energizing the circuit.

11. Be sure there is no danger to others should the motor unexpectedly start when you close the disconnects.

12. Remove your tags and close disconnects to energize circuit. Make the following checks:

    a) While holding Stop button depressed, press Start button. Nothing should happen.

    b) Press button - primary contactor should close and remain closed. Check direction of rotation.

    c) After first shorting contactor has closed, but before second contactor closes press Stop button. All contactors should open.

    d) After motor has stopped, press Start button and allow starting cycle to be completed. Make an accurate check of the time intervals for each step. If they are not equal, stop the motor, motor disconnect Off and reset the timer. Recheck, repeat until time intervals are the same.

13. Upon completion of job carefully dismantle equipment and be sure it is left in good condition for the next student.

Questions

1. Is the motor-running overcurrent protection connected in the circuit during the starting cycle?
2. Explain what would happen if one of the secondary resistors was open.
3. Why is it so important that magnetic controllers be mounted plumb?
4. How might the accelerating time of the starting cycle be automatically controlled to compensate for variations in the motor starting load?

References

American Electricians' Handbook, 8th Ed., Croft, Mc-Graw Hill

Electrical Motor Controls & Circuits, Fuchs & Garstang, Howard W. Sams and Co. Inc.

Electric Motor Controls, Aldrich, Delmar

National Electrical Code, N.F.P.A.

Electrical Motor Control Fundamentals, McIntyre

Job Sheet 10
Page 1 of 5

Synchronous Motor Starting

Objectives

1. Installation of a complete synchronous motor system with across the line starting.

2. Ability to apply N.E.C. requirements to work.

Materials Required

Motor and controller to be assigned by instructor
Other materials to be determined by student

Explanation

Squirrel cage and synchronous motor stators are very similar, but their rotors are not. The squirrel cage rotor develops a magnet field as a result of induced current from the revolving magnetic field of its stator. It is because of this induced field that the rotating torque is developed and the rotor cannot synchronize with the stator's rotating magnetic field. As synchronization is approached the induced field in the rotor is decreased thereby decreasing the torque and rotor speed. As the rotor speed decreases the induced field strength increases, increasing torque and speed. Therefore, varying the load of a squirrel-cage motor changes its speed.

The synchronous rotor has a small squirrel-cage winding built into it for starting purposes only. This winding is designed to allow the rotor to come as close as possible to the synchronous speed of the stator field. When this speed is reached the main rotor windings are energized with D.C. These D.C. windings provide the same number of poles in the rotor as there are in the stator. When these are energized with D.C. the rotor magnetic poles synchronize or lock-in-step with the rotating magnet poles of the stator. When the stator is energized the D.C. windings act as a secondary transformer and unless precautions are taken very high voltages may be developed. To prevent the high voltages the D.C. or field windings are connected across a field discharge resistor when not energized by the D.C.

An exciter-field rheostat is provided in the D.C. circuit to select the desired power factor after the motor is running at synchronous speed.

From this brief description it is evident that a starting control circuit and a synchronizing control circuit are required. They may be separate controllers, both control circuits combined in one controller; manual, push button or fully automatic. For starting an across the line starter or any method of reduced voltage starting may be used.

The line diagram with this job sheet is for an automatic synchronizing controller using an across-the-line starter. The polarized field-frequency relay)PFR) is used to determine when the D.C. supply should be connected to the rotor. If for any reason D.C. voltage is lost or the motor is overloaded to the point where the rotor pulls out of synchronization with the stator, the polarized frequency relay will open the D.C. excitation contactor and connect the rotor circuit across the discharge resistor.

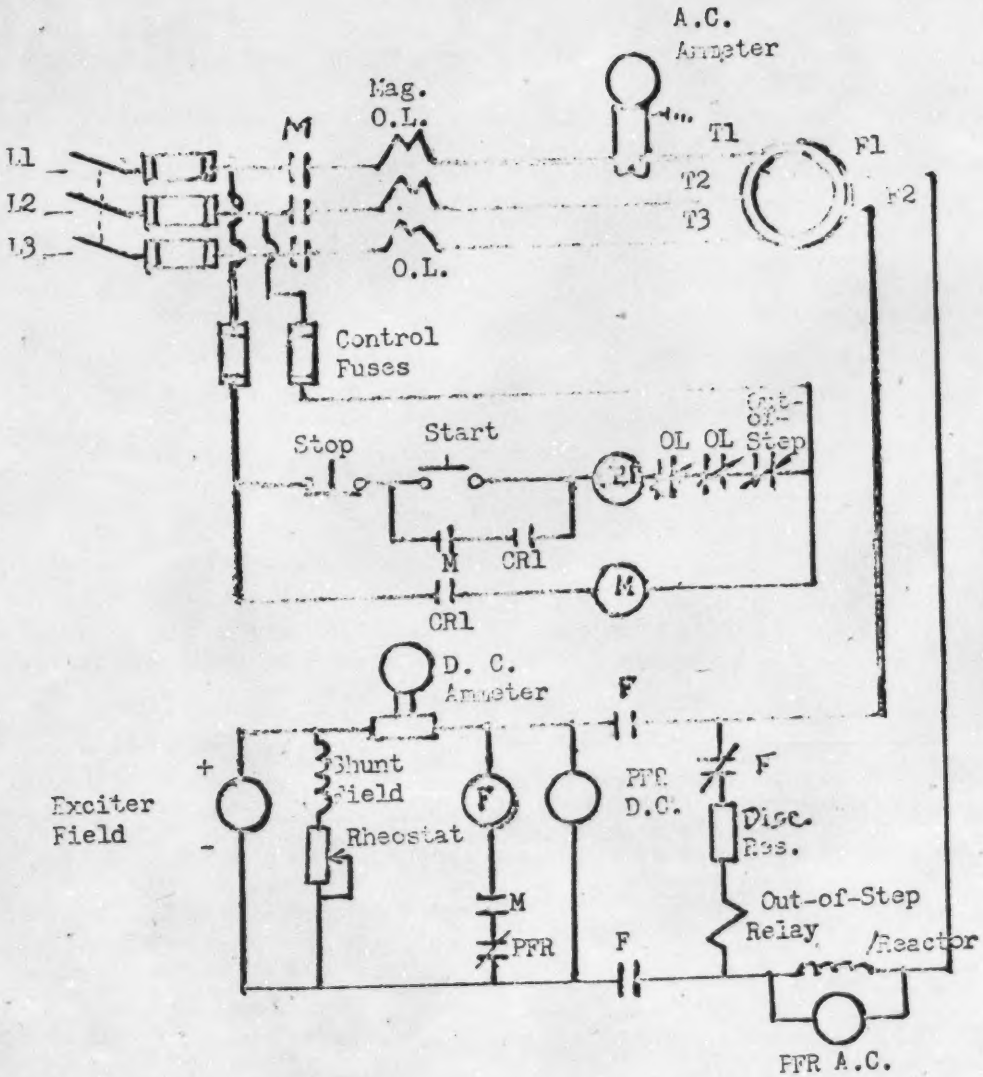
If the loss of voltage or the overload lasts long enough, five to seven seconds, the small squirrel-cage winding will overheat. To prevent this, an out-of-step relay is used to open the primary control. This is a timing relay connected in series with the discharge resistor so that when there is current in that part of the circuit timing is started. If contactor F does not operate within the time limit the relay opens the normally closed contacts in the control relay circuit.

Referring to the line diagram the sequence of operation is as follows: In starting the field winding is connected across the discharge resistor, out-of-step relay coil and A.C. part of polarized frequency relay through N.C. F contacts. Pressing the Start button completes the circuit to the pilot contactor (CRI) through control circuit fuses, Stop button and N.C. contacts of the overload and out-of-step relays. The closing of CRI energizes the line contactor (M), which connects the stator across the line. The holding circuits for coils CRI and M are established through normally open contacts CRI and M.

At the instant of starting, the polarized frequency relay (PFR) opens its normally closed contact and maintains an open circuit to the field contactor (F) until the motor accelerates to the proper speed for synchronizing. When synchronizing speed is reached the PFR relay completes the circuit for the field contactor coil (F) energizing the field winding with D.C. and opening the discharge resistance circuit. The normally closed contact (F) in the discharge resistor circuit is a late break type. This is to insure that the field windings are never left open.

The motor is now operating at synchronous speed. Pressing the Stop button or opening of an overload switch or out-of-step relay operation will disconnect the motor from the line.

If there is not an automatic synchronizing controller available two separate units may be used, a starter for primary control and a contactor for field control. The polarized field frequency relay, out-of-step relay and the control relay are not essential except in automatic control. The contactor used for controlling the field must have a normally closed, late break contact for the discharge circuit.


A.C.
Ammeter
Mag.
O.L.
M
T1
T2
T3
F1
F2
L1
L2
L3
O.L.
Control
Fuses
Stop
Start
OL OL
Out-
of-
Step
2T
M
CR1
CR1
M
D. C.
Ammeter
F
Exciter
Field
+
-
Shunt
Field
Rheostat
F
PFR
D.C.
F
Disc.
Res.
M
PFR
Out-of-Step
Relay
F
Reactor
PFR A.C.

Procedure

1. Read Information Sheets on A.C. Across the Line Controllers and Control Circuits.

2. Have instructor assign motor and controller.

3. Submit for approval a line diagram showing the sizes of equipment, wire and overcurrent prot-ction from feeder termination to motor.

4. Submit for approval a conduit diagram showing all equipment, conduit, and wire sizes as required by N.E.C.

5. Submit for approval a wiring diagram from feeder termination to motor, including secondary circuits.

6. After having diagrams approved, obtain materials and proceed to mount equipment.

   CAUTION: Be sure supply switch to your job is open and tagged. Using voltmeter, check load side of switch between phase legs and each phase leg to ground to be sure there is no voltage on your circuit conductors. At the same time check the line side of the switch to be sure the voltage to your circuit corresponds to the voltage ratings of your equipment.

7. Make the following checks after equipment is mounted:

   a) Proper ratings - voltage, current and size of starter.
   b) Contact surfaces in controller and push button station for proper alignment and condition of wear (i.e., pitted, burned, etc.).
   c) Proper contact tension.
   d) Free operation of all moving parts, push buttons, contacts, coil armatures, etc.
   e) Condition of flexible shunts.
   f) Condition of arc chutes or barriers.
   g) Worn or broken mechanical parts.
   h) Correct overload protection devices.
   i) Correct coil voltage.
   j) Check and compare the internal wiring of the controller with your diagram.

8. Proceed to wire all equipment and controls as shown in your approved diagrams.

9. After all wiring is completed and connections made, check the following:

   a) Connections and wiring correspond to your diagrams.
   b) All splices are mechanically and electrically tight and properly insulated.
   c) All terminal connections are tight.
   d) Wires do not interfere with moving parts.
   e) Motor properly lubricated and not binding.
   f) Discharge resistor is connected across field winding through contactor.

10. Have your instructor check the completed installation and secure his approval BEFORE energizing the circuit.

11. Be sure there is no danger to others should the motor unexpectedly start when you close the disconnects.

12. Remove your tag and close disconnects to energize circuit. Follow the directions given to you by your instructor to check out your particular type of control.

13. Upon completion of job carefully dismantle equipment and be sure it is left in good condition for the next student.

Questions

1. Explain the operation of the out-of-step relay. What other motor control circuits use a relay that is basically the same?

2. Explain why the field windings should never be open.

3. Why is it important that the field windings not be de-energized too long when line voltage is connected to the stator.

4. Using resource material explain how the polarized frequency relay functions.

References

Allen-Bradley Motor Control Catalog

Alternating Current Fundamentals, Duff, Delmar

American Electricians' Handbook, 8th Ed., Croft, McGraw-Hill

Controllers for Electric Motors, James and Markle, McGraw-Hill

Electrical Circuits and Machinery, Vol. II, A.C., Hehre and Harness, John Wiley and Sons

Electric Motor Controls, Aldrich, Delmar

National Electrical Code,

Electrical Motor Control Fundamentals, McIntyre